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ABSTRACT

Computer numerical control (CNC) has evolved from the first significant counting method--the abacus. Babbage had perhaps the greatest impact on the development of modern day computers with his analytical engine. Hollerith's functioning machine with punched cards was used in tabulating the 1890 U.S. Census. In order for computers to become a reality, the binary number system, Boolean algebra, and electromechanical circuitry, a system used by every digital computer, had to be discovered, invented, or developed. During World War II, IBM built a computer using simple electromechanical relays as on-off switching devices and punched tape to provide the necessary information to manipulate data. The 1950s saw the start of two related trends--building of a magnetic memory and development of the transistor. Through the 1960s, the integrated circuit, microcomputers, and memory chips were developed. Further advances in the chip, affordable computers, and software occurred in the 1970s. In 1976, CNC made its debut at the Chicago Trade Show. As computer chips became smaller and more powerful, the CNC machines could be used with almost any process involving X,Y,Z coordinates. Examples of contemporary CNC machines are the Bosto Matic Model 405, Cincinnati Milacron's Acramatic 760 G, and G.E.'s Fanuc Automation's CNC. Future developments will include more artificial intelligence and the clone-type brain. (YLB)

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A HISTORY OF COMPUTER NUMERICAL CONTROL

By Gilbert L. Haggen

In understanding CNC today, we must look at the past and see how CNC evolved from our predecessors who were men of great vision and curiosity.

As we look back in the window of time some 1500 years ago, we see perhaps the first significant counting method, the Abacus. Each bead on the ones rod was worth one. Each bead on the tens rod was worth 10 and so on. It was so efficient that it spread in its use to many lands and is still used even today by certain individuals. The **Abacus** had no competition until around the 17th century when a few intellectuals started to look at new and different ways of handling numbers and science. **John Napier** of Scotland, mathematician, designer , and theologian discovered **logarithms.** What a discovery. Now complex multiplication could be handled by addition. Then **William Aughtred** and other in 1620 developed the slide rule to handle calculations even more rapidly.

Pascal developed a device to add numbers quickly. His machine used a boxed wheel and cog device made up of wheels marked with ones, 10's, 100's and so on. His device was used for 300 years but could only be used to add numbers. Then in the same century, a genius by the name of **Gottfried Wilhelm** developed the first machine that could be used to subtract, multiply and divide numbers. He also co-discovered calculus and worked on the binary number system.

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Working with numbers had reached a point where they could be handled easily and quite efficiently. Then later, in the 18th century, **French silk weavers** started experimenting with perforated tape, punched cards and wooden drums to guide the looms through very complex movements. In 1804 **Joseph M. Jacquard** built a fully automatic loom that could handle very complex designs. The loom was controlled by many punched cards. Each punched card controlled a single thread through the shuttle. Jacquard's automated loom revolutionized the weaving industry, but the punch cards were to have their greatest impact in our century, in the computer field.

The great men of years ago had a tremendous impact in the development of our modern day computers. But perhaps the greatest was a man by the name of **Charles Babbage** who was a genius in his own right. He worked many years on his **"Difference Engine"**, made with toothed wheels on shafts turned by a crank, but it was never to be by Babbage. Then in **1833 Babbage** began work on an even more complex machine called the **"Analytical Engine"**. It was to be a machine of the most general nature, nothing less than a general purpose programmable computer. Even though the Analytical Engine was never built it paved the way for our modern day computer. Babbage's Difference Engine was later modified by **Pehr George Scheutz**, a Swedish inventor, and he demonstrated it in London in 1854.

Some nineteen years later, punched cards, an aspect of the Analytical Engine and weaving looms, appeared in a functioning machine built by **Herman Hollerith**, an American. The machine was used in tabulating the 1890 U.S. Census.

The **Hollerith's** cards were about the size of a dollar bill. Each card had 12 rows containing statistical data for the Census. The punched cards were pressed onto ranks of five pins and fed through the machine. A seven and a half year job was transformed into a six week count and a two and a half year statistical analysis. Hollerith formed the Tabulating Machine Company which later became the **International Business Machine Corporation, called IBM.**

In order for computers to become a reality, many things had to be accomplished, discovered and invented.

The binary number system had to be refined and developed into useable functions. **Gottfried W. Leibniz** invented the stepped wheel calculator. However he used the decimal system because the binary numbering system was to awsome to use. Leibniz also did alot of refinement on the binary number system, but never realized that the binary number system might be the all purpose language of logic.

In about 1816, some 125 years after Leibniz, a self taught British mathematician named **George Boole** did alot of research fo find a universal language. Boole wrote a paper in 1847 on the **"Mathematicl Analysis of Logic"**, and in 1854 he wrote another paper on **"An Investigation of the Laws of Thought"**. His analysis revolved around statements as being either true or false. The three most basic operations in Boolean algebra involved **AND, OR and NOT**. These three could be made to be either true or false, yes or no, open or closed, zero or one. Not many in the realm of science took Boole very serious and many

criticized his system, but it later turned out to be the universal language for computers.

Charles Pierce introduced Boolean algebra to the United States in 1867. He realized that the system could be used in electrical switching circuits so that they could be turned on or off, but he never built one, but did promote the idea. Pierce's introduction of Boolean Algebra finally took root in 1936, when **Claude Shannon**, a 21 year old American, bridged the gap between algebra theory and practical application. Shannon was asked by his major professor to study his complex analytical machine and see if he could make changes and write his masters thesis on the subject. Shannon reflected on his undergraduate work in Boolean Algebra and he definitely felt that electric circuits would be a definite improvement over oily gears and shafts. His thesis was published in 1938, it was a brilliant success and was used as the basis for the design of telephone systems. His thesis was a prime mover in the development of modern computer science. Ten years later, **Shannon** published another paper **"A Mathematical Theory of Communication"**. In his paper Shannon proposed a method of defining and measuring information in mathematical terms as true or false or yes or no choices, using binary digits. This idea was the very foundation for modern telecommunication and computer logic.

John Atanosoff in 1938 at Iowa State University had worked for several years on what type of logic could be used with his computer and he finally decided to use the binary number system. He built a prototype in 1939.

In 1936 **Konrad Zuse of Germany**, on his own genius, knowing nothing of Babbage, Stibitz and others, set out on his own to develop a computer using the binary number system. In 1939 he used 35 millimeter film with punched holes to drive his computer. Then the war came and a number of different scientists were working on various computing systems to assist in the war efforts.

George Stibitz built the first electromechanical circut using Boolean logic to control current flow as well as perform addition. It was the first of its kind in the U.S. This system is used by every digital computer. Later **Stibitz and Samuel Williams**, a Bell switching engineer, developed a device that could subtract, multiply, divide and add complex numbers. In January 1940, Stibitz connected several teletypes throughout the building to use the computer in doing calculations. It was the first network to be used in the U.S. and in Sept. of that same year he demonstrated by way of a terminal 250 miles away how remote-control in electromechanical computation could be handled.

During the war, IBM with the help of **Howard Aiken**, set to work in building a computer using simple electromechanical relays to serve as on-off switching devices, and punched tape provided the necessary instructions for manipulating the data. The major problem with Aiken's device was that he used the decimal system rather than the binary system. The machine was fifty-one feet long and 8 feet tall. It contained around 750,000 parts strung together with 500 miles of wire. The Mark I was officially introduced in August of 1944. The Navy used it to compute numbers up to 23 digits long. It could add or subtract

them in 3/10 of a second and multiply them in 3 seconds.

Zuse, in Germany, built several computers using the binary number system. Britain developed the **ULTRA**. The Electronic Numerical Integrated Computer **(ENIAC)** was built in the U.S. to solve problems. It was eighteen feet high and eighty feet long. One person viewed it as **"faster than thought"**. There were alot of changes made in the early computers but none had the far reaching impact that solid state devices had in the 50's. The early computers were big, slow, troublesome and very expensive.

The 50's saw the start of two related trends. the market for computers was increasing significantly. **Jay Forester** of MIT built a magnetic memory smaller and faster than existing vacuum tube computers.

When **Bell laboratory** developed the **transistor**, the old died and the new began to grow and flourish. Then in 1951 the **junction transistor** was introduced and it could do everything a tube could do, but it could do it quicker and at a fraction of the space. The first **transistor** was made out of **Germanium** which cost more than gold.

In **1954 Gordon Teal** of Texas Instruments discovered a way to make transistors out of Silicon. In **1954 IBM** introduced the first mass produced computer dubbed the 650.

In **1955 Bell labs** produced the first transistor computor containing 800 independent transistors.

In 1955 the first hint of the new age came when two numerical control machine tools were on display at the Chicago Amphitheatre. By 1960 NC was everywhere.

In **1958-1959** the integrated circuit was developed.

In 1959 **Kurt Lehoves** filed a patent for a **"Multiple Semi-Conductor Assembly"** whose components were separated from each other by P-N junctions. This system did not require the soldering of fine wires to each solid state device. Instead, a layer of metal was evaporated on top of the coating and down into tiny holes. This system was so efficient that Texas Instruments adopted it. In 1962, ICs were being mass produced by both Fairchild and Texas Instruments.

In 1959 Texas Instruments announced the birth of the **Integrated Circuit (IC)** and the Company built a computer containing 587 ICs for the Air Force.

In **1961 Digital Equipment** unveiled its PDP-8 the first commercially successful minicomputer for $20,000.

In **1968 Burroughs** produced the B2500 and the B3500 using the first integrated circuits.

In 1970 the first **memory chip** was produced that could store an entire kilobit of information. The old magnetic-core memories, held one bit of information: a one or a zero, yes or no. Thus, the new Intel chip replaced 1,024 cores occupying a space of 80 square inches.

The number of components being able to be placed on a chip moved into the thousands.

In the early 1970's the **MOS transistor (Metal Oxide Transistor)** came into widespread use and even more components could be placed on a chip. This procedure caused prices to come down considerably making computers within the price range of many people. This junction transistor comsumed less power and with

less heat circuitry consisting of up to 15 layers could be placed in a chip 4/1,000 of an inch thick.

In 1971 Ted Hoff designed the Intell 4004 microprocessor, containing all the basic parts of a central computer. It contained 2,250 components on one chip and could add two 4-bit numbers in 11 millionths of a second. It was used in the first micro-processor. It was a miracle the way they were able to get more in a limited space and be programmable. When linked with four other components containing memory, control and input-output circuitry, it yielded the microcomputer which was as powerful as the early 1950 mainframe computers.

In 1974 the Intel 8080 chip was developed and it contained 4500 components in one chip. It could add two 8-bit numbers in 2.5 millionths of a second, and it was the first general purpose microprocessor chip.

In 1974 Ed Roberts built a mail order microcomputer called the Altair. This computer was the first computer that people could afford to buy.

In 1975 the 6502 MOS chip was developed containing a few less components than the 8080 but it was faster and used extensively in home computers.

In 1975 the first software, using a form of basic, was developed by two students for use by Altair.

In 1976, CNC computer numerical control made its debut at the Chicago Trade Show . Computer Aided Design, (CAD), Computer Aided Manufacturing (CAM) and Computer Integrated Manufacturing (CIM) all became a part of manufacturing. Numerical control suddenly changed from a way of machine control, to a way of using

computers in manufacturing.

In 1977 the public had three new computers to choose from: **Apple II, Radio Shack TRS-80,** and **Commodore PET.**

In **1979 Software Arts** came out with the first business program: **Visi Calc.**

In **1979 Motorola** came out with its**68000 chip** containing 70,000 components and it could multiply two 16-bit numbers in 3.2 millionths of a second. It could perform multiplication as a single operation rather than as a repeated addition.

In **1980 Flexible Manufacturing Systems (FMS)** had their first introduction at the Chicago show. It confirmed that the computer had the power to give the type of control necessary to expeditiously handle part control. This became possible because the computer was getting smarter, more reliable, cost effective and more powerful than the main frame computer of just a few years ago. The smaller PCs opened up a whole new industry - manufacturing software. The PC could now show part design, tool paths, cutter offsets, tool lengths, and whole data bases to provide the operator with current up to date information.

By 1981 **Hewlett-Packard** introduced a **microprocessor** more powerful than the central processing units of many contemporary mainframe computers. It could multiply two 32-bit numbers in 1.8 millionths of a second. and the chip contained **450,000 MOS transistors.** Its size a mere 1/4th of an inch.

In **1981 IBM** entered the PC market.

Other very important chips include the **80286, 80386** and the newest to come out will be the **80486,** which will be so fast and

can store so quickly that only the bus bars and peripherals will limit its capabilities. IBM has been working on its OS2 for several years while others are developing faster and faster clockspeeds.

Steve Jobs is in the news again. He has unveiled a new computer with main frame capabilities costing about 6500.00. The resolution will be excellent and the speed will be extremely fast.

Commercial monolithic integrated circuits may soon contain both silicon and gallium-arsenide transistors which will be two to **three times faster** than comparable silicon devices.

An experimental manufacturing process called **X-ray lithography** is being used rather than ultraviolet or optical methods to produce computer chips. IBM scientists feel that the new memory chips will be able to contain **64M bits** of information by the mid 1990s rather than the 1M bit of information today. This will further enhance the capabilities of CNC. New methods of manufacture will continue to give more and more power to computer users.

In the 1990's, engneers forsee **VLSI (Very Large Scale Integration)** incorporating as many as **10 million components** on one fingernail-sized chip. Others see new **ceramic materials** capable of operating on photons or light particles, instead of on electrons. Some see growing the **"bio-chip"** a chunk of organic material in which each of the **billions of switches** can be contained in one molecule of protein.

Computers had their greatest change between 1975 and 1981. Minis got their start in the 60's but had a 6 figure price tag

and were still large. Leaving the masses unable to have their use.

With new, faster, and more efficient computers, CNC is progressing very rapidly in a very wide range of applications in industry, facilitating manufacturing tolerances and processess never possible before.

The first NC machine was built by MIT for the **Parsons Co.**, who was the principle sub-contractor for the Air Force. They used a hydrotel miller that was the start of the NC, CNC business.

The first numerical control machine used **hard wiring relays and tape readers.** The next generation used **vacuum tubes,** then, **transistors** and finally **integrated circuits.**

Direct Numerical Control (DNC) actually was used before CNC but a dedicated mini had to be used to download the programs. It was so expensive that users were not in favor of the system because of its limitations. When DNC reached its potential of being able to both download and upload its real potential came in being able to use local networks to run the many varied CNC machines. Now DNC is used in most major industries and it is now called **Distributed Numerical Control (CNC).**

As the computer chips became smaller and more powerful the CNC machines could be used with almost any process involving X,Y,Z coordinates as well as rotating axis, tilting head, etc.

Today, computers are able to communicate with other computers. Drawings can be generated on CAD and directly machined, by way of CAM eliminating alot of complex steps.

Every machine has had to have its own post-processors to

interpret the many different codes used by manufacturers. Today a part can be drawn in 3D, rotated, moved and all the coordinate points can be directly digitized and fed to the machine for machining. With closed loop systems, feedback can be obtained on tool wear, RPM, load no load conditions, defective tools, broken tools, and that information can be fed into the computer where changes can be made.

With computer controlled machines single machines have evolved into multiple machines with pallet control, self contained and automatically operated. The controller is only as good as the machine and many great innovations have been made in drive and table systems. The skill of the operator has been incorporated into the machine.

A typical example of the power of a CNC machine is as follows: **Bosto Matic Model 405** has a maximum spindle speed of **24,000 RPM (optional 40,000 rpm.) 0 to 100 ipm servo response in less that 12 milliseconds**, and control processing speed of 8 to 15 milliseconds. the A-axis has a maximum speed of 60 degrees per second and the B-axis can tilt up to 30 degrees per second, permitting 200 ipm simultaneous 5-axis contouring. The A-axis swing is 12 inches and the X-axis travel in 20 inches. Uses linear glass scales and ball screws with backlash compensation being standard. An 18-station Automatic Tool Changer (ATC) is available and a fully tested 5 axis post processor with total interfacing between CAD/CAM systems are available. A few years ago this was not possible but today it is standard.

Where CNC and PLC's are integrated into one package Multi-tasking (MT) and Computer Numerical Control (CNC) can control up

to 20 axis of motion and 2048 real I/O input/output points via a fiber-optic interface. It also supports digital AC servo drives and AC main spindle drives. The unit can control the operation of a loading robot, a series of independent, but related, single or multi-axis machine tools and an unloading robot while managing all the programmed interaction between them.

In addition to standard CNC features such as linear, circular, and mathematical interpolation, the unit offers contouring based on look-ahead program processing to control contouring speed and acceleration.

Cincinnati Milacron's new Acramatic 760 G computer control is designed for grinding parts of rotation in ID, OD, multi-surface, centerless, and center-type grinding machines. It features color graphics, touch screen, simplified logic diagram cycle representation, on line "help" for operators and service personnel, and enhanced communications for DNC/CIM via mainframe or PC's.

The new logic diagram cycle representation uses a real time layout of grinding functions in chart form to aid visualization. step one of the complex programming areas addressed by the control is automatic computation of interpolated moves involving three axis. For axes which are not perpendicular to one another, or which change orientation in-cycle, new feeds and speeds can be computed automatically by the control. It is a multi-tasking CNC. One program can be generated or edited while another program is running. The controller can store up to 999 programs and can be linked to other computers.

A standard support package provides comprehensive tool management programs for tracking grinding wheels, boring bar probes, and other tools used with the machine. The controller contains records of tools in use as well as tools which have been used, plus alot of other data base information.

G.E. Fanuc Automation's newest computer numerical control (CNC), offers a true 32-bit architecture for speed and accuracy, artifical intelligence (Al) based operator interface, as well as a compact modular design. The controller can integrate all of its control products, all controllers, programmable controllers, CNC's and industrial computers into MAP-compatible communication networks.

A multi-axis controller is used by Rolo-Con-II to control stepper motors at speeds of up to 300,000 steps per second. It offers servo motor control at speeds up to 3,000,000 encoder edges per second. The basic unit offers plus/minus one step control with its feedback circuitry and can provide standard robotic, CNC, or lead-thru software.

There are many good CAD/CAM programs and one is Plus Cam II, a PC based CAM system developed specifically for sculptured surface machining such as mold work, hydrofoils, and airfoils.

The software is able to define sculptured surfaces by multiple cross sections or by boundaries. Multiple paths can be defined and machined as a single surface, with the programming to generate pockets on sculptured surfaces, ruled surfaces, swept surfaces, (revolve a two dimensional shape around a third axis) and much more.

The software is designed to interface with CadKee and will

allow users to interface directly their (AI) drawing to CAM for CNC programming. then Plus Cam II will generate the necessary tool and cutter paths.

They also have a Master Cam PC based system which will allow quick and economical methods for generating three-axis programs. Part geometry can be created in Master Cam or downloaded from most major CAD systems such as AutoCad, VersaCad, Anvil, and CadKey.

Tomorrow will bring more artifical intelligence. The machine computer will be able to analyze a part in the 3D views, and start to make decisions from its huge library of similar part families. An operator will be able to converse with the machine, and obtain data from its many libraries. We will see the time when the computer will be able to make intelligent decisions in terms of setting cutting speeds, feeds, coolants and etc. The Vision systems will be better, allowing the machine to observe and do all the necessary moves.

Tomorrow also may bring us the clone type brain with many more capabilities than the existing chips. The computer brain will be grown through genetic engineering allowing the computer the capability of vision, sense, smell, and touch. Like the universe, its too vast to even comprehend. So will tomorrows CNC machine be. We have much to look forward to. All the acronyms of JIT, MAP, CIM, CAM, CNC, etc. will be handled by intelligent computers.